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TRANSLATOR'S DECLARATION

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I further declare that all statements made in this declaration of my own knowledge are true and that all statements made on information and belief and believed to be true; and further, that these statements are made with the knowledge that willful, false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful, false statements may jeopardize the validity of this application or any Patent issued thereon.

Junichi Matsuda

June 22, 2010
Date

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MAGNETIC DISK GLASS SUBSTRATE, MAGNETIC DISK, METHOD OF MANUFACTURING A MAGNETIC DISK GLASS SUBSTRATE AND METHOD OF MANUFACTURING A MAGNETIC DISK

Background of the Invention:

The present invention relates to a magnetic disk glass substrate and a magnetic disk that are used in a hard disk drive (HDD) which is a magnetic disk device, and methods for manufacturing the magnetic disk glass substrate and the magnetic disk.

At present, as a so-called IT industry is developing, dramatic innovation on information recording technology, particularly on magnetic recording technology, is desired. In a magnetic disk that is to be installed in a hard disk drive (HDD) which is a magnetic disk device used as a computer storage, the information recording density is being increased rapidly, unlike in other types of magnetic recording media, such as magnetic tapes and flexible disks. Accordingly, the information capacity which can be stored in a personal computer device is dramatically increasing on the strength of the increase in information recording density of the magnetic disk.

The magnetic disk has a magnetic layer and other layers on a substrate, such as an aluminum-based alloy substrate or a glass substrate. In a hard disk drive, while a magnetic head flies over the magnetic disk which is rotated at a high speed, the magnetic head records information signals as magnetized patterns on the magnetic layer, or reproduces the recorded information signals.

In recent years, following an increasing demand for mounting the hard disk drive in portable apparatuses (such as notebook personal computer devices) (for mobile use), attention is directed to a glass substrate which is a high strength and high stiffness material and which has high impact resistance as the magnetic disk substrate. In addition, the glass substrate can have a

smooth surface. Accordingly, it is possible to reduce the flying height of the magnetic head that records and reproduces information while flying over the magnetic disk. Thus, a magnetic disk having a high information recording density can be obtained.

However, the glass substrate is made of a brittle material. Accordingly, a variety of approaches have been proposed to strengthen the glass substrate. For example, Japanese Patent (JP-B) No. 2657967 (Reference Document 1) describes chemical strengthening in which the glass substrate is immersed in a mixed solution of KNO_3 and $NaNO_3$ for a predetermined time to substitute K^+ ions for Li^+ ions at surface layer portions of the glass substrate and thus to form compressive stress layers at the surface layer portions on both sides and a tensile stress layer between the compressive stress layers. In Reference Document 1, the maximum tensile stress of the tensile stress layer is desirably 4 kg/mm^2 or less.

Japanese Patent (JP-B) No. 3254157 (Reference Document 2) discloses that, when the glass substrate chemically strengthened by the same method as that in Reference Document 1 has a thickness of 0.5 mm to 1.0 mm, the compressive stress layers desirably have a thickness of 30 μm to 100 μm and a compressive stress of 2 kg/mm^2 to 15 kg/mm^2 with the tensile stress layer having a tensile stress of 1.5 kg/mm^2 or less.

In the meanwhile, the information recording density of the magnetic disk has recently increased to a level exceeding 40 gigabits per square inch. Further, a super high recording density exceeding 100 gigabits per square inch is about to be realized. The recent magnetic disk achieving such a high information recording density can store a practically sufficient amount of information even if a disk area is very small as compared with known magnetic disks.

As compared with other information recording media, the magnetic disk

has an extremely high information recording and reproduction speed (response speed). It is therefore possible to record and reproduce information anytime.

Attention has been directed to these various features of the magnetic disk. As a result, in recent years, there arises a demand for a small-sized hard disk drive adapted to be installed in an apparatus having a housing much smaller than that of a personal computer and required to have a high response speed, such as a so-called cellular phone, a digital camera, a portable information apparatus (for example, a PDA (personal digital assistant)), or a car navigation system. Specifically, in highly mobile apparatuses, such as cellular phones, digital cameras, portable MP3 players, portable information apparatuses such as PDA's, or on-vehicle apparatuses such as car navigation systems, there is a demand for a small hard disk drive equipped with a magnetic disk using a substrate having, for example, a diameter of 50 mm or less or of 30 mm or less and a thickness of less than 0.5 mm or of 0.4 mm or less.

The small hard disk drive used in these portable or so-called mobile apparatuses is always exposed to impulsive force such as impact from falling or vibration. Accordingly, in these applications, it is required to further improve impact resistance of each internal component of the hard disk drive, including a magnetic disk, in order to enhance the reliability.

The magnetic disk using a glass substrate is useful as a magnetic disk for hard disk drives used in the portable apparatuses. This is because the glass substrate made of glass as a hard material has high stiffness as compared with a substrate made of metal as a soft material and because desired strength can be achieved by a means such as chemical strengthening as described above.

Summary of the Invention:

Accordingly, an object of the present invention is to provide a magnetic disk glass substrate suitable for a small hard disk drive capable of being installed in highly mobile apparatuses, such as cellular phones, digital cameras,

portable MP3 players, portable information apparatuses such as PDA's, or on-vehicle apparatuses such as car navigation systems.

Another object of the present invention is to provide a magnetic disk glass substrate which is not broken even if an impact of, for example, 2000 G or more is applied to a small hard disk drive.

Still another object of the invention is to provide a magnetic disk using the above-mentioned magnetic disk glass substrate.

The inventors of the present invention have found causality between fracture failure of magnetic disks during the drop test or the like of hard disk drives and the manufacture process of magnetic disk glass substrates, particularly a chemical strengthening step, and have conducted intensive research about enhancement the impact resistance of the glass substrate.

The inventors found a variety of difficulties encountered in manufacture of a small glass substrate to be installed in small hard disk drives, in comparison with the manufacture of glass substrates for generally known so-called 2.5 inch hard disk drives or 3.5 inch hard disk drives.

Specifically, it has been found that, in small and thin glass substrates with a diameter of 50 mm or less and a thickness of less than 0.5 mm, sufficient strength can not be obtained merely by known techniques and that failure of magnetic disks, such as fracture, cannot be certainly prevented in some cases.

The inventors continued the research in order to solve the above-mentioned problem. As a result, the inventors found that the above-mentioned problem can be overcome by appropriately determining and controlling chemical strengthening conditions in the manufacture process of the magnetic disk glass substrate.

The present invention includes the following aspects.

(First Aspect)

A magnetic disk glass substrate according to the present invention has a

disk thickness of less than 0.5 mm so as to be installed in 1 inch hard disk drives or hard disk drives using a smaller-diameter magnetic disk than that used in the 1 inch hard disk drive, the glass substrate having a predetermined disk thickness by lapping both main surfaces, the both main surfaces being subjected to polishing so that the both main surfaces are mirror-finished surfaces with no cracks, the glass substrate being subjected to chemical strengthening to form compressive stress layers with thicknesses d1 and d2 at surface layer portions adjacent to the both main surfaces and a tensile stress layer with a thickness L between the compressive stress layers, a product L·Pt of a thickness L of the tensile stress layer measured by observing a longitudinal section of the magnetic disk glass substrate by the Babinet compensator method and a maximum tensile stress Pt of the tensile stress layer being not smaller than 0.4 kg/mm and not greater than 2.0 kg/mm.

That is, the magnetic disk glass substrate satisfies the following relationship.

$0.4 \text{ [kg/mm]} \leq L \cdot Pt \leq 2.0 \text{ [kg/mm]}$

From the disk thickness T after the chemical strengthening, calculation may be made by "L = {T - (d1 + d2)}". Preferably, however, the thickness L of the tensile stress layer is directly measured.

(Second Aspect)

In the magnetic disk glass substrate of the first aspect of the present invention, the thickness L of the tensile stress layer is 0.4 mm or less, and the maximum tensile stress Pt of the tensile stress layer is 10 kg/mm^2 or less.

That is, the magnetic disk glass substrate satisfies the following relationship:

$L \leq 0.4$ (mm)

$Pt \leq 10$ (kg/mm^2)

(Third Aspect)

In the magnetic disk glass substrate of the first aspect of the present invention, a total thickness D of a thickness d1 of the compressive stress layer formed adjacent to one of the main surfaces and a thickness d2 of the compressive stress layer formed adjacent to the other main surface is 40% or more with respect to the disk thickness T.

That is, the magnetic disk glass substrate satisfies the following relationship:

$(D/T) \geq 0.4$

(Fourth Aspect)

In the magnetic disk glass substrate of the third aspect of the present invention, the maximum tensile stress Pt of the tensile stress layer is 10 kg/mm^2 or less.

That is, the magnetic disk glass substrate satisfies the following relationship:

$Pt \leq 10$ [kg/mm^2]

(Fifth Aspect)

In the magnetic disk glass substrate of the first aspect of the present invention, a maximum compressive stress Pc of the compressive stress layers is 4 kg/mm^2 or more.

That is, the magnetic disk glass substrate satisfies the following relationship:

$Pc \geq 4$ [kg/mm^2]

(Sixth Aspect)

The magnetic disk glass substrate of the first aspect of the present invention is used for a magnetic disk installed in a hard disk drive that performs start and stop operations by a load/unload system.

(Seventh Aspect)

A magnetic disk according to the present invention includes the magnetic

disk glass substrate according to the first aspect, and at least a magnetic layer formed on the magnetic disk glass substrate.

(Eighth Aspect)

A method for manufacturing a magnetic disk glass substrate according to the present invention is adapted to manufacture the magnetic disk glass substrate according to the first aspect and includes a chemical strengthening step, a glass substrate is brought into contact with melted nitrates containing at least three kinds of alkali metal elements in the chemical strengthening step, so that the compressive stress layers are formed at the surface layer portions adjacent to the both main surfaces of the glass substrate by low-temperature ion exchange and that the tensile stress layer is formed between the compressive stress layers.

(Ninth Aspect)

The method for manufacturing the magnetic disk glass substrate of the eighth aspect of the present invention includes a polishing step, an abrasive cloth and the glass substrate being relatively moved in the polishing step while colloidal silica abrasive grains or diamond abrasive grains are fed, thereby removing cracks in the both main surfaces of the glass substrate to form mirror-finished surfaces.

(Tenth Aspect)

In the method for manufacturing the magnetic disk glass substrate of the ninth aspect of the present invention, the main surfaces are processed in the polishing step into the mirror-finished surfaces having an arithmetic mean roughness (Ra) of 0.4 nm or less.

(Eleventh Aspect)

A method for manufacturing a magnetic disk according to the present invention includes using a magnetic disk glass substrate manufactured by the method according to the eighth aspect and forming at least a magnetic layer on

a main surface of the magnetic disk glass substrate.

In the magnetic disk glass substrate according to the present invention, where d1 and d2 represent the thicknesses of the compressive stress layers formed at surface layer portions adjacent to the both main surfaces by chemical strengthening, L represents the thickness of the tensile stress layer, and Pt represents the maximum tensile stress, the product L·Pt of the thickness of the tensile stress layer and the maximum tensile stress is not smaller than 0.4 kg/mm and not greater than 2.0 kg/mm. Therefore, it is possible to realize excellent impact resistance.

In the above-mentioned magnetic disk glass substrate, by setting the thickness L of the tensile stress layer at 0.4 mm or less, or by setting the total thickness D of the thickness d1 of the compressive stress layer formed adjacent to one of the both main surfaces and the thickness d2 of the compressive stress layer formed adjacent to the other main surface at 40% or more relative to the disk thickness T, it is possible to realize excellent impact resistance.

In the above-mentioned magnetic disk glass substrate, by setting the maximum tensile stress Pt of the tensile stress layer at 10 kg/mm^2 or less, it is possible to simultaneously achieve excellent impact resistance and durability.

In the above-mentioned magnetic disk glass substrate, by setting the maximum compressive stress Pc of the compressive stress layer at 4 kg/mm^2 or more, it is possible to realize excellent impact resistance.

The magnetic disk of the present invention includes the above-mentioned magnetic disk glass substrate and at least the magnetic layer formed on the glass substrate. Therefore, it is possible to provide the magnetic disk having excellent impact resistance and durability. The magnetic disk can be favorably used as a magnetic disk to be installed in a hard disk drive that performs start and stop operations by a load/unload system.

Accordingly, the present invention is suitable for small hard disk drives

that can be installed in highly mobile apparatuses, such as cellular phones, digital cameras, portable MP3 players, portable information apparatuses such as PDA's, or on-vehicle apparatuses such as car navigation systems. It is possible to provide a magnetic disk glass substrate that is not broken even if an impact of, for example, 2000 G or more is applied to the hard disk drive. It is also possible to provide a magnetic disk using such a magnetic disk glass substrate.

Brief Description of the Drawings:

Fig. 1 is a sectional view showing the profile of stress layers at a section of a magnetic disk glass substrate according to the present invention.

Fig. 2 is a graph plotting the result of an impact test for the magnetic disk glass substrate.

Detailed Description of the Invention:

Now, preferred embodiments of the present invention will be described in detail with reference to the drawings.

A magnetic disk glass substrate of the present invention is manufactured by lapping (grinding) main surfaces of a glass plate to prepare a glass base material, cutting the glass base material into a glass disk, and at least polishing main surfaces of the glass disk.

As the glass plate to be lapped in the present invention, glass plates of a variety of shapes may be used. The shape of the glass plate may be a rectangular shape or a disk shape. Disk-shaped glass plates can be lapped with a lapping machine conventionally used in the manufacture of magnetic disk glass substrates, and can be reliably processed at low cost.

The glass plate must be larger than the magnetic disk glass substrate to be manufactured. For example, when a magnetic disk glass substrate for a magnetic disk to be installed in a 1 inch hard disk drive or a smaller hard disk drive is manufactured, the magnetic disk glass substrate has a diameter of

about 20mm to 30 mm. Accordingly, the disk-shaped glass plate has a diameter of 30 mm or more, preferably 48 mm or more. In particular, if a disk-shaped glass plate with a diameter of 65 mm or more is used, it is possible to obtain, from one glass plate, a plurality of magnetic disk glass substrates for magnetic disks to be installed in 1 inch hard disk drives. This is advantageous in view of mass production. The upper limit in size of the glass plate need not be particularly limited. In case of the disk-shaped glass plate, it is preferable to use the glass plate having a diameter of 100 mm or less.

The glass plate may be manufactured, for example, by using molten glass as a material and using a known manufacturing method, such as pressing, floating, or fusion. Among these methods, use of pressing can provide the glass plate at low cost.

As a material of the glass plate used in the present invention, no particular limitation is imposed as long as the glass plate can be chemically strengthened. Preferably, aluminosilicate glass is used. In particular, lithium-containing aluminosilicate glass is preferable. Aluminosilicate glass makes it possible to precisely form compressive stress layers having an appropriate compressive stress and a tensile stress layer having an appropriate tensile stress by ion-exchange chemical strengthening, particularly low-temperature ion-exchange chemical strengthening. Therefore, aluminosilicate glass is particularly preferable as a material of the chemically strenghthened glass substrate for a magnetic disk.

Preferably, the aluminosilicate glass has a composition mainly containing 58 to 75 weight % of SiO_2, 5 to 23 weight % of Al_2O_3, 3 to 10 weight % of Li_2O, and 4 to 13 weight % of Na_2O.

More preferably, the aluminosilicate glass has a composition mainly containing 62 to 75 weight% of SiO_2, 5 to 15 weight % of Al_2O_3, 4 to 10 weight % of Li_2O, 4 to 12 weight % of Na_2O, and 5.5 to 15 weight % of ZnO_2,

with a weight ratio (Na_2O/ZnO_2) of 0.5 to 2.0 between Na_2O and ZnO_2 and a weight ratio (Al_2O_3/ZnO_2) of 0.4 to 2.5 between Al_2O_3 and ZnO_2.

In order to remove protrusions at the surface of the glass disk resulting from undissolved ZnO_2, it is preferable to use a glass suitable for chemical strengthening which contains 57 to 74% of SiO_2, 0 to 2.8% of ZnO_2, 3 to 15% of Al_2O_3, 7 to 16% of Li_2O, and 4 to 14% of Na_2O, in mol %.

By chemical strengthening, such aluminosilicate glass is increased in flexural strength and is excellent in Knoop hardness.

The lapping is carried out in order to increase the profile accuracy (for example, flatness) and dimensional accuracy (for example, accuracy in thickness) of a main surface of the workpiece or the glass plate. The lapping is performed by pressing a grind stone or a surface plate against the main surface of the glass plate and relatively moving the glass plate and the grinding stone or the surface plate, thereby grinding the main surface of the glass plate. The lapping may be performed with a double side lapping machine using a planetary gear system.

In the lapping, it is preferable to supply the main surface of the glass plate with a grinding fluid to wash sludge (grinding dust) out of the ground surface and to cool the ground surface. A slurry prepared by adding free abrasive grains to the grinding fluid may be fed to the main surface of the workpiece to grind the main surface.

The grinding stone used in the lapping may be a diamond grinding stone. As the free abrasive grains, hard abrasive grains, such as alumina abrasive grains, zirconia abrasive grains, or silicon carbide abrasive grains, may preferably be used.

The lapping improves the profile accuracy of the glass plate and forms the glass base material having the main surface of a planarized shape and a thickness reduced to a predetermined value.

In the present invention, the main surface of the glass base material is planarized and the thickness is reduced by the lapping. As a result, it is possible to obtain the glass disk from the glass base material by cutting the glass base material. Thus, in the present invention, it is possible to prevent occurrence of defects, such as chipping, cracking, and fracturing, when the glass disk is obtained by cutting the glass base material.

For example, the flatness of the glass base material with an area of 7088 mm^2 (area of a circle with a diameter of 95 mm) is preferably 30 μm or less, more preferably 10 μm or less. The thickness of the glass base material is preferably 2 mm or less, more preferably 0.8 mm or less. If the glass base material has a thickness of less than 0.2 mm, the glass base material itself may not endure the load applied during the step of obtaining the glass disk by cutting. Therefore, the glass base material preferably has a thickness of 0.2 mm or more. On the other hand, if the glass base material has a thickness of more than 2 mm, cutting may not be accurately carried out because the thickness is too large and defects, such as chipping, cracking, and fracturing, may occur when the glass disk is obtained by cutting.

The glass base material must have a size greater than that of the magnetic disk glass substrate to be manufactured. For example, when a magnetic disk glass substrate for a magnetic disk to be installed in a 1 inch hard disk drive or a smaller hard disk drive is manufactured, the magnetic disk glass substrate has a diameter of about 20mm to 30 mm. Accordingly, the glass base material has a diameter of 30 mm or more, preferably 48 mm or more. In particular, if a glass base material with a diameter of 65 mm or more is used, it is possible to obtain, from one glass base material, a plurality of glass disks as magnetic disk glass substrates for magnetic disks to be installed in 1 inch hard disk drives. This is advantageous in view of mass production. The upper limit in size of the glass base material need not be particularly limited. In case of the

disk-shaped glass base material, the diameter is preferably 100 mm or less.

The glass base material may be cut by using a cutting blade or a grinding stone containing a harder material than glass, such as a diamond cutter or a diamond drill. Alternatively, the glass base material may be cut by using a laser cutter. However, accurate cutting with the laser cutter may be difficult for small glass disks with a diameter of 30 mm or less. In this case, cutting is easily carried out with a cutting blade or a grinding stone.

Herein, as a size of the glass disk obtained by cutting from the glass base material, a diameter of 30 mm or less is particularly suitable. In the present invention, the glass disk obtained by cutting from the glass base material is at least polished to mirror-finish the main surface of the glass disk.

By the polishing, cracks in the main surface of the glass disk are removed and the surface roughness of the main surface is reduced to, for example, 5 nm or less in R_{max} and 0.4 nm or less in arithmetic mean roughness (Ra). When the glass disk has the main surface as the mirror-finished surface, it is possible to prevent occurrence of so-called crash failure or thermal asperity failure in the magnetic disk manufactured by using the glass disk even if a magnetic head has a flying height of, for example, 10 nm. When the glass disk has the main surface as the mirror-finished surface, it is possible, in the chemical strengthening which will later be described, to perform uniform chemical strengthening in microregions of the glass disk and to prevent delayed fracture due to microcracks.

The polishing may be carried out, for example, by pressing a surface plate with an abrasive cloth (for example, a polishing pad) adhered thereto against the main surface of the glass disk, and relatively moving the glass disk and the surface plate while polishing liquid is fed to the main surface of the glass disk, thereby polishing the main surface of the glass disk. Herein, the polishing liquid preferably contains abrasive grains. For example, colloidal silica

abrasive grains may be used as the abrasive grains. Desirably, the abrasive grains having an average grain size of 10nm to 200 nm are used.

Alternatively, as the polishing, use may be made of, for example, a tape polishing technique in which a tape-shaped abrasive cloth (for example, an abrasive tape) is pressed against the main surface of the glass disk, and the glass disk and the abrasive cloth are relatively moved while polishing liquid is fed to the main surface of the glass disk, thereby polishing the main surface of the glass disk. Herein, the polishing liquid preferably contains abrasive grains. As the abrasive grains, diamond abrasive grains may be used. Preferably, the abrasive grains having an average grain size of 10nm to 200 nm are used.

The abrasive surface of the polishing pad or the abrasive tape used in the present invention is preferably formed of a resin material, such as polyurethane or polyester. Preferably, the polishing pad has an abrasive surface formed of resin foam (for example, polyurethane foam) and the abrasive tape has an abrasive surface formed of resin fiber (for example, polyester fiber).

In the present invention, the glass disk is preferably subjected to lapping before polishing. This lapping is performed in the manner similar to the above-mentioned lapping of the glass plate. By polishing the glass disk after lapping, the mirror-finished main surface can be obtained in a shorter time.

In the present embodiment, an end face of the glass disk is preferably mirror-polished. As the end face of the glass disk has a shape as a cross section, the end face is polished into a mirror-finished surface. As a result, it is possible to suppress occurrence of particles and to successfully prevent thermal asperity failure in the magnetic disk manufactured by using the magnetic disk glass substrate. In addition, when the end face is the mirror-polished surface, it is possible to prevent delayed fracture resulting from microcracks. Preferably, as the mirror-finished state of the end face, the mirror-finished surface having an arithmetic mean roughness (Ra) of 100 nm or less is preferable.

In the present invention, chemical strengthening is performed before and/or after the step of polishing the glass disk. By performing the chemical strengthening, it is possible to produce a high compressive stress at the surfaces of the magnetic disk glass substrate so as to improve the impact resistance. In particular, when aluminosilicate glass is used as a material of the glass disk, chemically strengthening can be favorably carried out.

As the chemical strengthening in the present invention, no particular limitation is imposed as long as any known chemical strengthening technique is used. The chemical strengthening of the glass disk is carried out by, for example, bringing the glass disk into contact with a heated chemical strengthening molten salt to perform ion exchange substituting the ions of the chemical strengthening salt for the ions at the surface layer of the glass disk.

As the ion exchange, low-temperature ion exchange, high-temperature ion exchange, surface crystallization, or glass surface dealkalization is known. In the present invention, it is preferable to use low-temperature ion exchange in which ion exchange is performed in a temperature range not higher than the annealing point of the glass.

In the low-temperature ion exchange, alkali ions in the glass are replaced by different alkali ions having an ion radius larger than that of the alkali ions in a temperature range not higher than the annealing point of the glass. Consequently, the volume of the ion-exchanging portion is increased to produce a compressive stress at the surface layer of the glass. Thus, the surface layer of the glass is strengthened.

In the chemical strengthening, the molten salt is preferably heated to a temperature of 280°C to 660°C, particularly 300°C to 400°C, in order to successfully perform ion exchange.

The time during which the glass disk is in contact with the molten salt is preferably several hours to several tens of hours.

Preferably, the glass disk is preheated to a temperature of 100°C to 300°C before the glass disk is brought into contact with the molten salt. After the chemical strengthening, the glass disk is processed into a product (magnetic disk glass substrate) through cooling and cleaning steps.

A material of a treatment bath for carrying out the chemical strengthening is not particularly limited as long as the material is excellent in corrosion resistance and low in dust generation. The chemical strengthening salt or chemical strengthening molten salt has oxidizing properties and the treatment temperature is high. Therefore, it is necessary to suppress damage and dust generation by selecting the material excellent in corrosion-resistance and to thereby suppress thermal asperity failure or head crash. In view of the above, as a material of the treatment bath, a quartz material is particularly preferable. Besides, use may be made of a stainless steel material, a corrosion-resistant martensitic or austenitic stainless steel material. The quartz material is superior in corrosion resistance, but is expensive. Therefore, an appropriate material may be selected in view of profitability.

As a material of the chemical strengthening salt in the present invention, use is preferably made of a nitrate containing an alkali metal element, such as a nitrate containing potassium nitrate, sodium nitrate, or lithium nitrate. A lithium element contained in the nitrate preferably has a content of 10 ppm to 2000 ppm. If lithium ions are excessively contained in the chemical strengthening molten salt, ion exchange is inhibited. Consequently, it may become difficult to obtain desired tensile stress and compressive stress to be obtained in the present invention. When the glass, particularly the lithium-containing aluminosilicate glass, is chemically strengthened by the above-mentioned chemical strengthening salt, it is possible to achieve a desired stiffness and impact resistance of the magnetic disk glass substrate.

As the magnetic disk glass substrate of the present invention which is

manufactured as mentioned above, a glass substrate for a thin magnetic disk with a disk thickness of less than 0.5 mm, particularly a disk thickness of 0.1 to 0.4 mm, is suitable. Further, as the magnetic disk glass substrate, a glass substrate for a small magnetic disk with a disk diameter (outer diameter) of 30 mm or less is particularly suitable. This is because such a thin or small magnetic disk is installed in a 1 inch hard disk drive or a hard disk drive smaller than the 1 inch hard disk drive. Thus, the magnetic disk glass substrate is suitable as a magnetic disk glass substrate to be installed in 1 inch hard disk drives or smaller hard disk drives than the 1 inch hard disk drives.

The magnetic disk glass substrate for manufacture of the magnetic disk to be installed in the 1 inch hard disk drive has a diameter of about 27.4 mm and a disk thickness of 0.381 mm. The magnetic disk glass substrate for manufacture of the magnetic disk to be installed in the 0.85 inch hard disk drive has a diameter of about 21.6 mm.

In a magnetic disk according to the present invention, a magnetic layer formed of a cobalt (Co) based ferromagnetic material may be used as a magnetic layer formed on the magnetic disk glass substrate. In particular, the magnetic layer made of a cobalt-platinum (Co-Pt) or cobalt-chromium (Co-Cr) ferromagnetic material that can produce a high coercive force is preferable. As a method of forming the magnetic layer, DC magnetron sputtering may be used.

An underlayer or the like may be interposed between the glass substrate and the magnetic layer, if appropriate. As a material of the underlayer, an Al-Ru alloy or a Cr-based alloy may be used.

On the magnetic layer, a protective layer for protecting the magnetic disk against the impact from the magnetic head may be formed. As the protective layer, use is preferably made of a hard hydrogenated carbon protective layer.

In addition, a lubricating layer of a PFPE (perfluoro polyether) compound may be formed over the protective layer to alleviate the interference between

the magnetic head and the magnetic disk. The lubricating layer may be formed by application, for example, using dipping.

(Examples)

The present invention will be described in detail by using Examples and Comparative Examples. However, the invention is not limited to the structures of the Examples.

(Example 1: Method for manufacturing a magnetic disk glass substrate)

A method for manufacturing a magnetic disk glass substrate in the present Example, which will hereinafter be described, includes the following steps (1) to (7):

(1) rough lapping step (rough grinding step)

(2) shaping step (peripheral lapping step)

(3) precision lapping step (precision grinding step)

(4) end-face mirror-finishing (polishing) step

(5) first polishing step

(6) second polishing step

(7) chemical strengthening step

First, a disk-shaped glass base material of amorphous aluminosilicate glass was prepared. The aluminosilicate glass contains lithium. The aluminosilicate glass has a composition of 63.6 weight% of SiO_2, 14.2 weight% of Al_2O_3, 10.4 weight% of Na_2O, 5.4 weight% of Li_2O, 6.0 weight% of ZnO_2, and 0.4 weight% of Sb_2O_3.

(1) Rough lapping step

A 0.6 mm thick glass sheet made from molten aluminosilicate glass was used as the glass base material. From the glass sheet, a disk-shaped glass disk with a diameter of 28.7 mm and a thickness of 0.6 mm was obtained using a grinding stone.

As a method of forming the glass sheet, use is generally made of a down

draw process or a float process. Besides, the disk-shaped glass base material may be obtained by direct press. The aluminosilicate glass as a material of the sheet glass must contain 58 to 75 weight % of SiO_2, 5 to 23 weight % of Al_2O_3, 4 to 13 weight % of Na_2O, and 3 to 10 weight % of Li_2O.

Then, the glass disk was subjected to the lapping step in order to improve the dimensional accuracy and the profile accuracy. The lapping step was performed using a double side lapping machine with abrasive grains having a grain size of #400.

Specifically, both surfaces of the glass disk housed in a carrier were lapped to a surface accuracy of 0 to 1 μm and a surface roughness (R_{max}) of about 6 μm by using alumina abrasive grains having a grain size of #400 and rotating a sun gear and an internal gear with a load set at about 100 kg.

(2) Shaping step

Then, a hole having a diameter of 6.1 mm was formed at a center portion of the glass disk using a cylindrical grinding stone and the outer peripheral end face was ground to reduce the diameter to 27.43 mm. Subsequently, the outer and the inner peripheral end faces were chamfered in a predetermined manner. At this time, the surface roughness of the end faces of the glass disk was about 4 μm in R_{max}.

Generally, in a 2.5 inch HDD (hard disk drive), a magnetic disk having an outer diameter of 65 mm is used.

(3) Precision lapping step

Then, after changing the grain size of the abrasive grains into #1000, the main surfaces of the glass disk were lapped. As a result, the surface roughness of the main surfaces was about 2 μm in R_{max}, and about 0.2 μm in Ra.

By carrying out the precision lapping step, it is possible to reduce microroughness formed on the main surfaces in the rough lapping step and the shaping step as preceding steps.

After the precision lapping step, the glass disk was subjected to ultrasonic cleaning by successively dipping the glass disk in cleaning baths of a neutral detergent and water with ultrasonic waves applied thereto.

(4) End-face mirror-finishing (polishing) step

Next, the end faces of the glass disk were polished with a brush while the glass disk was rotated, so that the surface roughness of the end faces (inner and outer peripheral end faces) of the glass disk was about 40 nm in Ra.

After the end-face mirror-finishing, the main surfaces of the glass disk were rinsed with water.

In the end-face mirror-finishing (polishing) step, glass disks are stacked and their end faces are polished. In order to prevent formation of flaws at the main surfaces of the glass disks, this step is preferably performed before the first polishing step which will later be described or before and after the second polishing step.

By the end-face mirror-finishing (polishing) step, the end faces of the glass disk were processed into a mirror-finished state so as to prevent generation of dust such as particles. After the end-face mirror-finishing (polishing) step, the diameter of the glass disk was measured. As a result, the diameter was 27.4 mm.

(5) First polishing step

Then, the first polishing step was performed using a double side polishing machine in order to remove flaws and strain left in the precision lapping step mentioned above.

In the double side polishing machine, the glass disk held by a carrier was placed between and brought into tight contact with upper and lower surface plates to which polishing pads are adhered. The carrier was engaged with a sun gear and an internal gear and the glass disk was clamped and pressed between the upper and the lower surface plates. Then, while a polishing liquid

was fed between the abrasive surfaces of the polishing pads and the main surfaces of the glass disk, the sun gear was rotated so that the glass disk rotated on its axis on the surface plates and revolved around the internal gear. Thus, the both main surfaces were simultaneously polished.

The same double side polishing machine was used in the following Examples. Specifically, the first polishing step was performed using polyurethane foam as the polishing pad. As regards a polishing condition, a polishing liquid comprising cerium oxide and RO water was used. After the first polishing step, the glass disk was subjected to ultrasonic cleaning and drying by successively dipping the glass disk in cleaning baths of a neutral detergent, pure water (1), pure water (2), IPA (isopropyl alcohol), and IPA (vapor drying).

(6) Second polishing step

As a mirror-polishing step of the main surfaces, the second polishing step was performed by using a double side polishing machine similar to that used in the first polishing step and changing the polisher into a soft polishing pad (polyurethane foam).

The second polishing step is carried in order to remove cracks certainly while maintaining the flat main surfaces obtained by the above-mentioned first polishing step and to process the main surfaces into mirror-finished surfaces with the surface roughness Ra reduced to, for example, about 0.4 to 0.1 nm.

As a polishing liquid, a polishing liquid comprising colloidal silica abrasive grains (average grain size of 80 nm) and RO water was used. The load was set at 100 g/cm^2 and the polishing time was 5 minutes.

After the second polishing step, the glass disk was subjected to ultrasonic cleaning and drying by successively dipping the glass disk in cleaning baths of a neutral detergent, pure water (1), pure water (2), IPA (isopropyl alcohol), and IPA (vapor drying).

(7) Chemical strengthening step

Then, after the cleaning, the glass disk was subjected to chemical strengthening. The chemical strengthening was performed by using a chemical strengthening molten salt prepared by mixing potassium nitrate, sodium nitrate, and lithium nitrate to obtain a chemical strengthening salt and melting the chemical strengthening salt. The lithium content was measured with an ICP emission analyzer.

The chemical strengthening solution was heated to 340°C to 380°C. The glass disk after cleaning and drying was dipped in the chemical strengthening solution for about 2 to 4 hours, thereby performing the chemical strengthening. During dipping, in order to chemically strengthen the entire surface of the magnetic disk glass substrate, a plurality of magnetic disk glass substrates were housed in a holder so that their end faces are held.

By arbitrarily selecting the chemical strengthening conditions, the strength of the glass disk and the profile of the stress layer were arbitrarily controlled and a plurality of samples were prepared. The following table 1 shows the conditions for preparation of the samples.

Table 1

Sample Preparing Conditions

Samples	Treating temperature [°C]	Treating time [hour]	Lithium concentration [ppm] of chemical strengthening salt
1	340	2	10
2	340	2	2000
3	340	4	10
4	340	4	2000
5	380	2	10
6	380	2	2000
7	380	4	10
8	380	4	2000
9	450	4	10
10	no treatment	no treatment	no treatment

After the chemical strengthening, the magnetic disk glass substrate was dipped in a water bath of 20°C to be rapidly cooled and was held for about 10 minutes.

After rapid cooling, the magnetic disk glass substrate was cleaned by dipping the glass substrate in concentrated sulfuric acid heated to about 40°C. After sulfuric acid cleaning, the magnetic disk glass substrate was subjected to ultrasonic cleaning and drying by successively dipping the glass substrate in cleaning baths of pure water (1), pure water (2), IPA (isopropyl alcohol), and IPA (vapor drying).

Then, the main surfaces of the magnetic disk glass substrate after cleaning were subjected to visual inspection and subsequently to thorough examination using optical reflection, scattering, and transmission. As a result, protrusions resulting from adhered matters or defects such as flaws were not found at the main surfaces of the magnetic disk glass substrate.

The surface roughness of the magnetic disk glass substrate obtained via the above-mentioned steps was measured by an atomic force microscope (AFM). As a result, it was confirmed that extremely smooth mirror-finished surfaces were formed with R_{max} of 2.5 nm and Ra of 0.30 nm. The values representing the surface roughness were calculated in accordance with Japan Industrial Standard (JIS) B0601 from the surface geometry measured by the atomic force microscope (AFM).

Further, the magnetic disk glass substrate thus obtained had an inner diameter of 7 mm, an outer diameter of 27.4 mm, and a thickness of 0.381 mm. It was confirmed that these dimensions were predetermined dimensions of the magnetic disk glass substrate for use in the 1 inch magnetic disk.

The inner peripheral end face defining the circular hole in the magnetic disk glass substrate had surface roughness of 40 nm in Ra and 50 nm in Ra at

the side wall portion. The outer peripheral end face had surface roughness of 40 nm in Ra at the chamfered portion and 70 nm in Ra at the side wall portion. Thus, it was confirmed that the inner peripheral end face was mirror-finished as well as the outer peripheral end face.

The main surfaces of the magnetic disk glass substrate thus obtained were precisely analyzed with an electron microscope. As a result, it was confirmed that the main surfaces was mirror-finished surfaces with no cracks. By mirror-polishing the main surfaces with colloidal silica abrasive grains (average grain size of 80 nm), smooth mirror-finished surfaces with Ra of 0.30 nm were formed.

As the main surfaces, the mirror-finished surfaces with Ra of about 0.1 nm to 0.4 nm and with no cracks are formed so that delayed fracture of the chemically strengthened glass can be prevented more certainly.

On the surfaces of the magnetic disk glass substrate, foreign matters or particles causing thermal asperities were not observed. On the inner peripheral end face around the circular hole, foreign matters or cracks were not observed.

(Measurement of stress layers)

The magnetic disk glass substrate thus obtained was cut into a rectangular piece with a width of about 3 mm so as to expose the cross-section surfaces perpendicular to the main surfaces. Then, both of the cross-section surfaces (sections of the substrate) of the piece were ground and polished with an abrasive and a polishing pad so that the distance between the cross-section surfaces was reduced to about 0.5 mm.

Fig. 1 is a sectional view of the profile of the stress layers at a section of the magnetic disk glass substrate.

The profile of the stress layers at a section of the magnetic disk glass substrate is obtained as shown in Fig. 1 by measuring the exposed section of the magnetic disk glass substrate with a Babinet compensator method.

The Babinet compensator is an instrument including two opposing quartz wedges with the same angle. One of the wedges is shifted in the direction of its length by a screw of a micrometer. The two wedges have optical axis directions perpendicular to each other and a movable prism has an axis extending in the shifting direction. This instrument is widely used for inspection of delay in phase difference (retardation) of crystals and the degree of double refraction, for inspection of glass with internal stress, etc.

As regards the profile of the stress layer, the following definitions are made.

T: thickness (total thickness) [mm] of magnetic disk glass substrate

d1, d2: thickness (depth) [mm] of compressive stress layers (stress layer depth)

D (= d1 + d2): total thickness [mm] of compressive stress layers

L (= T - (d1 + d2)): thickness [mm] of tensile stress layer

Pc: compressive stress (compression stress) [kg/mm^2]

Pt: tensile stress [kg/mm^2]

(Impact resistance test)

The magnetic disk glass substrate thus obtained was subjected to the impact test. The impact test was performed by fixing the magnetic disk glass substrate to a special impact test jig, by applying impacts of pulsed sine half waves successively from 1000 G to 5000 G to the magnetic disk glass substrate in the direction perpendicular to the main surfaces, and by observing the state of fracture of the magnetic disk glass substrate.

As a product specification of the hard disk drive (HDD), it is presently required to endure 2000G. Therefore, in order to assure a sufficient margin, the magnetic disk glass substrate which can endure the impact of 3000G, with 50% margin, in the impact test is regarded as an acceptable product. The result of the impact test is shown in the following Table 2.

Table 2

As will be understood from the result of the impact test, if {T - (d1 + d2)}·Pt, i.e., L·Pt is 0.4 [kg/mm] or less, the impact of 3000G can not be endured. It is found out that, for those samples with L·Pt greater than 2.0 [kg/mm], the delayed fracture is caused to occur.

Fig. 2 is a graph plotting the result of the impact test for the magnetic disk glass substrate.

Thus, in order that the magnetic disk glass substrate endures the impact of 3000 G and that no delayed fracture is caused to occur, the following relationship must be satisfied as shown in Fig. 2.

0.4 [kg/mm] $\leq L \cdot Pt \leq 2.0$ [kg/mm]

In the magnetic disk glass substrate, if the thicknesses d1 and d2 of the compressive stress layers are insufficient, the impact resistance is reduced. Accordingly, the following relationship must be satisfied.

$L \leq 0.4$ [mm] (where $L < T$)

From the viewpoint of ensuring the sufficient thicknesses d1 and d2 of the compressive stress layers, the following relationship may be satisfied.

$(D/T) \geq 0.4$

If the thicknesses d1 and d2 of the compressive stress layers are excessively large, the tensile stress of the tensile stress layer is excessively strong, which may induce delayed fracture. Therefore, practically, the following relationship is desirably satisfied.

$(D/T) \leq 0.55$

In the magnetic disk glass substrate, if the compressive stress Pc of the compressive stress layers is insufficient, the impact resistance is reduced. Therefore, the following relationship must be satisfied.

$Pc \geq 4$ [kg/mm^2]

In order to prevent delayed fracture, the tensile stress Pt of the tensile stress layer may satisfy the following relationship.

$Pt \leq 10$ [kg/mm^2]

Magnetic disk glass substrates were similarly manufactured by arbitrarily selecting various chemical strengthening conditions in the manner similar to that mentioned above and were subjected to the impact resistance test at 4000 G in order to assure 100% margin in the impact resistance. As a result, it was found that, if L·Pt is 0.5 or more, the impact of 4000 G can be endured. It was also found that, if L·Pt is 1.0 or less, delayed fracture is prevented.

(Example 2: Method for manufacturing a magnetic disk)

Next, the magnetic disk was manufactured through the following steps.

On each of the main surfaces of the magnetic disk glass substrate obtained by the above-mentioned steps, an Al-Ru alloy seed layer, a Cr-W alloy underlayer, a Co-Cr-Pt-Ta alloy magnetic layer, and a hydrogenated carbon protective layer were successively formed by the use of a DC magnetron sputtering apparatus of a static opposed-target type. The seed layer exhibits a function of miniaturizing magnetic grains of the magnetic layer, and the underlayer exhibits a function of orienting the easy magnetization axis of the magnetic layer in the in-plane direction.

The magnetic disk at least includes the magnetic disk glass substrate as a nonmagnetic substrate, the magnetic layer formed on the magnetic disk glass substrate, the protective layer formed on the magnetic layer, and a lubricating layer formed on the protective layer.

The nonmagnetic metal layer (nonmagnetic underlayer) comprising the seed layer and the underlayer is formed between the magnetic disk glass substrate and the magnetic layer. In the magnetic disk, those layers except the magnetic layer are made of nonmagnetic materials. In the present Example, the magnetic layer and the protective layer are formed in contact with each other, and the protective layer and the lubricating layer are formed in contact with each other.

Specifically, at first, the Al-Ru (aluminum-ruthenium) alloy seed layer having a thickness of 30 nm was deposited on the magnetic disk glass substrate by sputtering with an Al-Ru alloy (Al: 50 at%, Ru: 50 at%) used as a sputtering target. Then, the Cr-W (chromium-tungsten) alloy underlayer having a thickness of 20 nm was deposited on the seed layer 5 by sputtering with a Cr-W alloy (Cr: 80 at%, W: 20 at%) used as a sputtering target. Then, the Co-Cr-Pt-Ta (cobalt-chromium-platinum-tantalum) alloy magnetic layer having a thickness of 15 nm was deposited on the underlayer by sputtering with a Co-Cr-Pt-Ta alloy (Cr: 20 at%, pt: 12 at%, Ta: 5 at%, balance being Co) used as a sputtering target.

Then, on the magnetic layer, the protective layer of hydrogenated carbon was formed. Furthermore, the lubricating layer of PFPE (perfluoro polyether) was formed by dipping. The protective layer exhibits a function of protecting the magnetic layer against the impact from the magnetic head. Thus, the magnetic disk was obtained.

The magnetic disk thus obtained was subjected to a glide test using a glide head having a flying height of 10 nm. As a result, no colliding foreign matter was found and a stable flying state could be maintained. The magnetic disk was further subjected to a record/reproduction test at 700 kFCI. As a result, a sufficient signal-to-noise ratio (S/N ratio) was obtained. No signal error was confirmed.

The magnetic disk was installed in a 1 inch hard disk drive requiring an information recording density of 60 gigabits or more per square inch and was driven. As a result, recording and reproduction were successfully carried out without problems. Specifically, neither crash failure nor thermal asperity failure occurred.

In the present invention, no particular limitation is imposed on the diameter (size) of the magnetic disk glass substrate. Particularly, however, the present invention exhibits an excellent advantage in case where a small-diameter magnetic disk glass substrate is manufactured. The small-diameter magnetic disk glass substrate mentioned herein is a glass substrate for use in, for example, the magnetic disk having a diameter of 30 mm or less.

The small-diameter magnetic disk with a diameter of, for example, 30 mm or less is used for a storage in on-vehicle apparatuses such as car navigation systems or portable apparatuses such as PDA's and mobile phone terminal units, and is required to have high durability and impact resistance as compared with general magnetic disks installed in apparatuses used in a fixed state.

CLAIMS:

1. A magnetic disk glass substrate having a disk thickness of less than 0.5 mm so as to be installed in a 1 inch hard disk drive or hard disk drives using a smaller-diameter magnetic disk than that used in the 1 inch hard disk drive, wherein:

the glass substrate having a predetermined disk thickness by lapping both main surfaces, the both main surfaces being subjected to polishing so that the both main surfaces are mirror-finished surfaces with no cracks,

the glass substrate being subjected to chemical strengthening to form compressive stress layers at surface layer portions adjacent to the both main surfaces and a tensile stress layer between the compressive stress layers;

a product of a thickness of the tensile stress layer measured by observing a longitudinal section of the magnetic disk glass substrate by the Babinet compensator method and a maximum tensile stress of the tensile stress layer being not smaller than 0.4 kg/mm and not greater than 2.0 kg/mm.

2. The magnetic disk glass substrate according to claim 1, wherein:

the thickness of the tensile stress layer is 0.4 mm or less, and

the maximum tensile stress of the tensile stress layer is 10 kg/mm^2 or less.

3. The magnetic disk glass substrate according to claim 1, wherein:

a total thickness of a thickness of the compressive stress layer formed adjacent to one of the main surfaces and a thickness of the compressive stress layer formed adjacent to the other main surface is 40% or more with respect to the disk thickness.

4. The magnetic disk glass substrate according to claim 3, wherein:

the maximum tensile stress of the tensile stress layer is 10 kg/mm^2 or less.

5. The magnetic disk glass substrate according to claim 1, wherein:

a maximum compressive stress of the compressive stress layers is 4 kg/mm^2 or more.

6. The magnetic disk glass substrate according to claim 1, wherein:

the magnetic disk glass substrate is used for a magnetic disk installed in a hard disk drive that performs start and stop operations by a load/unload system.

7. A magnetic disk comprising:

the magnetic disk glass substrate according to claim 1, and

at least a magnetic layer formed on the magnetic disk glass substrate.

8. A method for manufacturing a magnetic disk glass substrate, the method being adapted to manufacture the magnetic disk glass substrate according to claim 1, the method comprising:

a chemical strengthening step;

a glass substrate being brought into contact with melted nitrates containing at least three kinds of alkali metal elements in the chemical strengthening step;

so that the compressive stress layers are formed at the surface layer portions adjacent to the both main surfaces of the glass substrate by low-temperature ion exchange; and

that the tensile stress layer is formed between the compressive stress layers.

9. The method for manufacturing a magnetic disk glass substrate according to claim 8, comprising:

a polishing step;

an abrasive cloth and the glass substrate being relatively moved in the polishing step while colloidal silica abrasive grains or diamond abrasive grains are fed, thereby removing cracks in the both main surfaces of the glass

substrate to form mirror-finished surfaces.

10. The method for manufacturing the magnetic disk glass substrate, according to claim 9, wherein:

the main surfaces are processed in the polishing step into mirror-finished surfaces having an arithmetic mean roughness (Ra) of 0.4 nm or less.

11. A method for manufacturing a magnetic disk, comprising using a magnetic disk glass substrate manufactured by the method according to claim 8 and forming at least a magnetic layer on the main surface of the magnetic disk glass substrate.

Abstract of the Disclosure:

By chemical strengthening, surface layer portions adjacent to both surfaces become compressive stress layers and a tensile stress layer is formed between the compressive stress layers. The thickness of a glass substrate is less than 0.5 mm. When a thickness of the tensile stress layer is represented by L and a tensile stress of the tensile stress layer is represented by Pt (kg/mm^2), the relationship:

$$0.4\ [kg/mm] \leq L \cdot Pt \leq 2.0\ [kg/mm]$$

is satisfied.

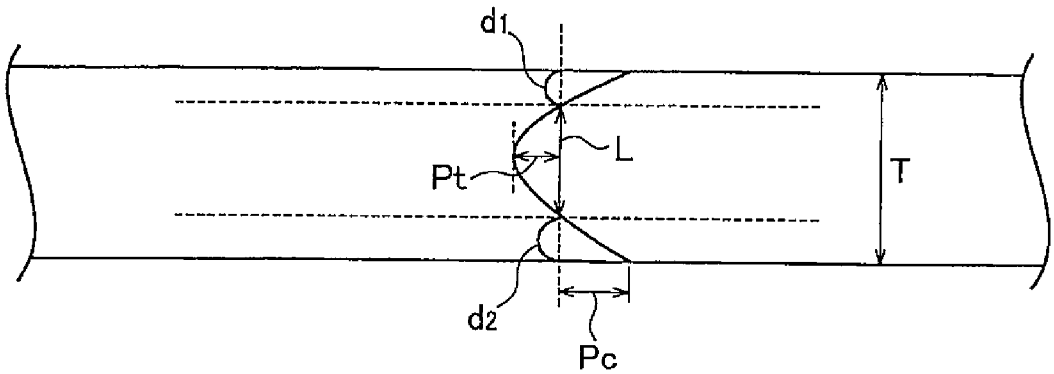
d1
L
Pt
T
d2
Pc

FIG. 1

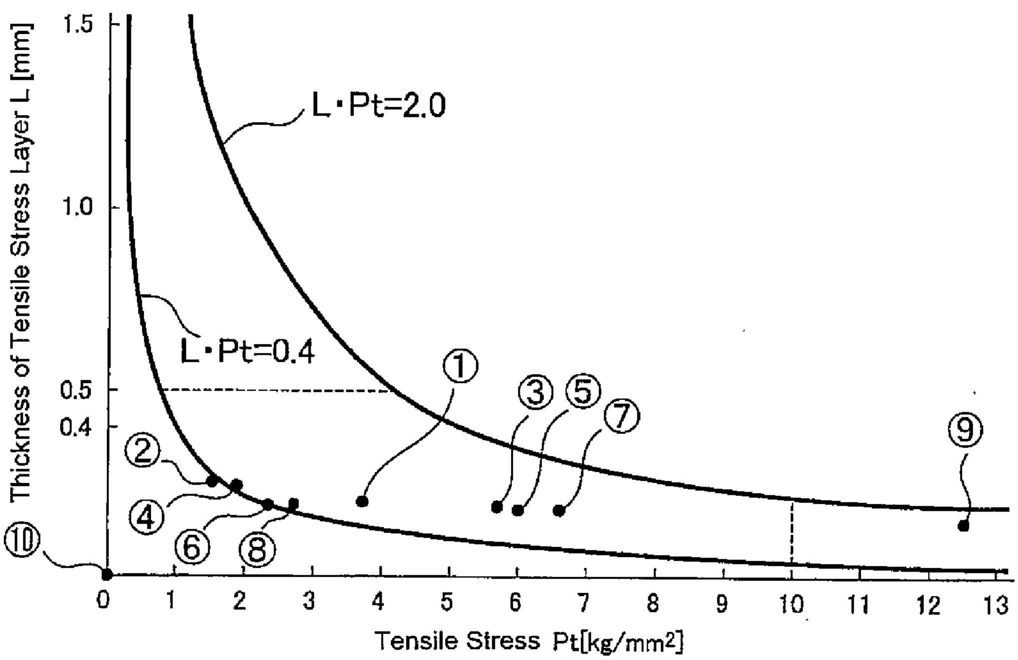
Thickness of Tensile Stress Layer L [mm]
1.5
1.0
0.5
0.4
L・Pt=2.0
L・Pt=0.4
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Tensile Stress Pt[kg/mm2]

FIG. 2